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U. S. ARMY

Technical Memorandum 1-63

EFFECTIVENESS OF THE V-51R EAR PLUG WITH IMPULSE PRESSURES UP TO 8 psi

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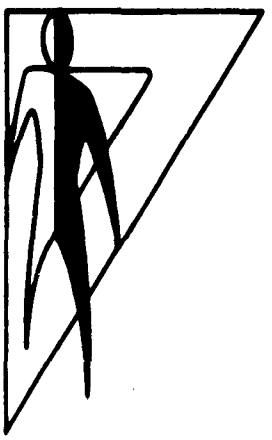
HUMAN ENGINEERING LABORATORIES



ABERDEEN PROVING GROUND,
MARYLAND

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ABSTRACT

The protection which the V-51R Ear Plug provides against high-intensity impulse noise was determined for simulated rapid-fire field conditions. Twenty enlisted men were exposed to 2, 4, and 6 pounds per square inch peak overpressures generated by a 105mm howitzer. Their temporary threshold shifts were then measured at 2000 and 4000 cycles per second. The results indicated that inserting the V-51R Ear Plug without checking its fit does not give adequate protection to all personnel. It was also found that a protection-checked ear (ear plug inserted to minimize the level of a reference sound) gave adequate protection with impulse pressures up to 8 psi.

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WITH IMPULSE PRESSURES UP TO 8 psi

INTRODUCTION

The blast of medium artillery weapons (105mm and 155mm howitzers with muzzle brakes) creates peak overpressures of seven to nine pounds per square inch (psi). Such overpressures can cause temporary hearing losses and even permanent ear damage to the crews operating these weapons. This situation is undesirable because of the tactical considerations involved, the welfare of the individual soldier, and the possible cost to the government for disability payments.

The V-51R Ear Plug was designed to provide protection against loud noise. Much research has been done to find out how effective it is. Most of this work, however, has dealt with the problems of continuous noise and transient noise where peak pressures generated by the impulses were below 1.5 psi (3, 4). The problem of protection against higher impulse pressures (up to and including 8 psi) has not previously been investigated.

The purpose of this study was to determine whether the V-51R Ear Plug will meet the U. S. Continental Army Command (CONARC) requirement of providing adequate ear protection to personnel who are associated with weapons that can produce instantaneous peak overpressures up to 8 psi.

Recovery from temporary hearing loss follows an exponential curve, with 50 percent recovery occurring in the first two minutes (11). Although individual differences preclude establishing any hard-and-fast relationship between peak hearing loss and time to complete recovery, rough estimates can be made from available data. Peak losses of 60 to 80 decibels (dB) require a week or more for complete recovery; 30 to 40 dB, one or two days; and 20 dB or less, a few hours (12). Reports also indicate that the auditory threshold at various frequencies is differentially affected by temporary threshold shift (TTS). The

greatest loss from gun blast appears at frequencies above 100 cps (2). This permitted establishment of a safety criterion which was used with the test subjects. It was decided that a TTS greater than 50 dB at 2000 or 4000 cps two minutes after exposure, or incomplete recovery one week after exposure, would necessitate removing the subject from the study to avoid the risk of permanent damage. Each subject's measures were considered individually, rather than combined with other subject's TTSs.

EXPERIMENTAL DESIGN

In order to determine the effects of multiple rounds and different impulse pressures simultaneously, a two-group-by-three treatment design was used in the first part of the study. The subjects were divided into two groups and matched with respect to individual auditory acuity. The members of one group were exposed to five rounds, and the members of the other were exposed to ten rounds. All subjects were exposed to three successively higher impulse pressure levels. This part of the study simulated field conditions in that there were no controls to insure the proper insertion of the ear plugs.

The number of rounds by exposure pressure of the first part of study is shown in the matrix below:

	Exposure Pressures		
Group	2 psi	4 psi	6 psi
I	5 rounds	5 rounds	5 rounds
II	10 rounds	10 rounds	10 rounds

The second part of the study used a two-group-by-two treatment design to simultaneously determine the effects of multiple rounds on protected versus unprotected ears. Half of each group from Part One of the study was exposed to a higher peak pressure with properly installed ear plugs, while the other half was exposed to 1.5 psi (8, "Protection is ... essential for pressures above one and a half pounds").

The number of rounds by exposure pressures of the second part is shown in the matrix below:

Group	Exposure Pressures: 8 psi with plugs	Exposure Pressures: 1.5 psi without plugs
I	5 rounds	5 rounds
II	10 rounds	10 rounds

Effects of factors due to age, tendency toward TTS, and initial hearing sensitivity were controlled by equating the experimental groups. The tendency toward TTS included effects of a subject's initial exposure to the muzzle-brake blast, such as psychological trauma, and adequacy of ear-plug fit.

The effects of time of day on the number-of-rounds treatment were minimized by alternately exposing pairs of men from the 5- and 10-round groups.

SUBJECTS

Thirty-two enlisted men from various First and Second Army installations were used as subjects. Upon arrival at Aberdeen Proving Ground, each was given an ear examination, which included an air conduction audiogram, and was fitted with the V-51R Ear Plug at the outpatient clinic of the U. S. Army Hospital. The audiograms were obtained by a medical technician at the Eye, Ear, Nose, and Throat Clinic, using a Model H-1 Maico Audiometer in a Model 400-A soundproof booth. The audiometer had been calibrated one month earlier at the Medical Depot Facilities, St. Louis, Missouri.

Ten men were dropped prior to exposure. Five were rejected due to a history of ear infection, sinus trouble, or an active infection discovered during the preliminary medical examination. The other five were rejected because they did not have normal hearing (15 dB or better) in both ears at 4000 cps.

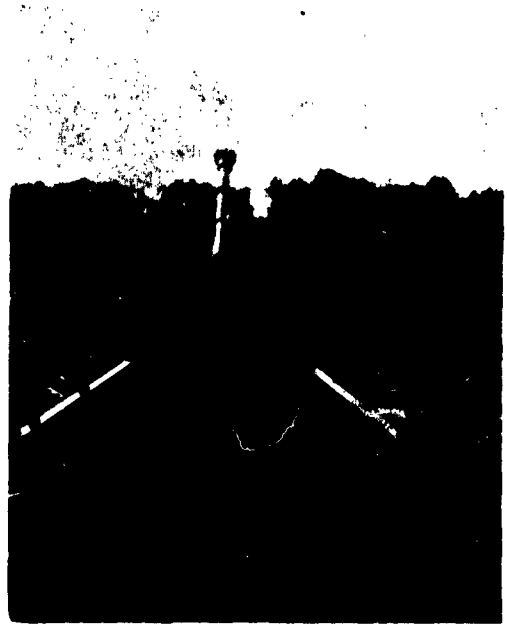

Fig. 1. REAR VIEW OF THE EMPLACED 105mm HOWITZER WITH LOW-EFFICIENCY MUZZLE BRAKE DURING PIEZOELECTRIC GAUGE MEASUREMENTS FOR 6 psi POSITION.

Fig. 2. THE THREE AVAILABLE SIZES OF V-51R EAR PLUGS - SMALL, MEDIUM, AND LARGE.

All subjects had Class A profiles except for vision. They ranged in age from 17 to 24 years, with a mean of 21.2 years. Their mean time in service was 11.5 months, with a range of four to 28 months.

EQUIPMENT

Ear Plug

"The V-51R ... is a lightweight ear plug shaped to fit the average ear canal and compliant enough to conform readily to most of the irregularities of individual ears" (10). (Federal Stock Numbers are 6515-299-8288, large size; 6515-299-8289, medium size; and 6515-299-8290, small size.) (Fig. 2)

Sound Source

The impulse noise for this study was generated by the weapon described below, which was fired at an elevation of 35 degrees, with the upper blast shields folded and the lower shield unfolded (Fig. 1).

Howitzer, 105mm, M2A2E2, Number 23429
Tube, 105mm, M2A2E2, Number 56803
Carriage, 105mm, M2A2E2, Number 1
Recoil Mechanism, 105mm, M2A4, Number 16903
Muzzle Brake, 105mm, Low Efficiency, No. 8

The ammunition consisted of the following with a propelling charge equivalent to a Charge Zone Number 10 (service charge):

Projectile, M1, Empty, Inert
Propellant, T36, MP, .042 inch web
Primer, Percussion, M28B2
Fuze, Dummy, M73
Case, Cartridge, M14, Resized

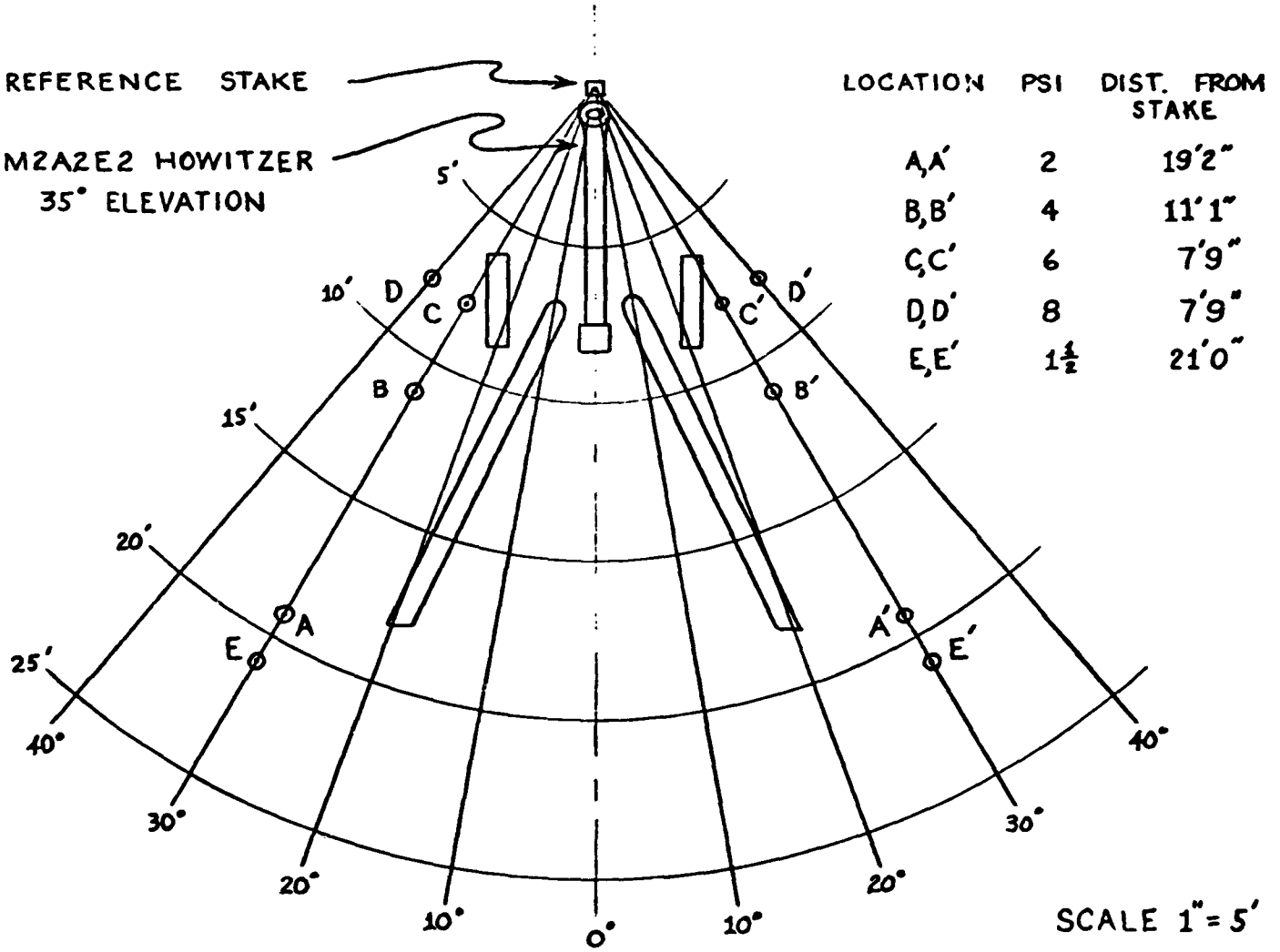

Fig. 3. POSITIONS OF SUBJECTS DURING FIRINGS.

Impulse Measurements

Piezoelectric, pencil-type gauges were used to measure the shock front profiles to determine the location of the desired peak over-pressures. Positions used in the study are shown in Figure 3. See Appendix A for the method and theory of measuring blast and pressure gradients.

Audiometers

Four Rudmose Automatic Audiometers, Model ARJ-4, Serial Numbers 1037, 1052, 1054, and 1214 were used (Fig. 4). They are discrete frequency Békésy-type instruments which normally record left then right ear auditory thresholds at 500, 1000, 2000, 3000, 4000, and 6000 cps. Modifications were made to facilitate the checking of 2000 and 4000 cycles, respectively, before and after the two-minute point on the audiogram card. This was accomplished by the use of a rotary switch wired to enable the operator to test 4 kc on the right ear, 4 kc on the left ear, 2 kc on the right ear, 2 kc on the left ear, or the normal pattern. An attenuation switch was also added to allow the operator to lower the sound level 0 dB, 10 dB, or 20 dB. The attenuator switch made it possible to check very low threshold levels, on the order of -30 dB.

The audiometers were checked against one another by means of repeated threshold measurements of the same subject; they were found to be within $\pm$ 5 dB of one another. The two machines that were best matched -- in terms of giving identical 2000 and 4000 cps readings -- were used for the firing site measurements. The other two were used for the two- and four-hour post-exposure checks.

Audiometer Rooms and Sound Booths

Two conventional tractor-trailer vans were used to administer audiograms to the subjects at the firing site and near their barracks. The insides of the vans were lined with target cloth draped in gathers on a ratio of three-to-one to provide sound absorption and insulation. Each subject was tested with his head within a booth. The booths, similar in shape to open telephone booths, were constructed of acoustical ceiling tile which further reduced the noise level (Fig. 5). The ambient noise level inside the vans was analyzed by octave bands and found to be within the levels recommended for background noise in audiometer rooms for 2000 and 4000 cps threshold testing requirements (1).

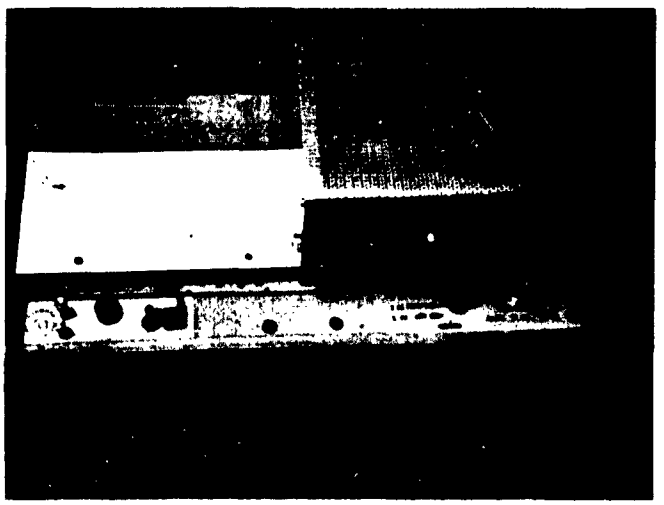

Fig. 4. OPERATOR CONTROLS OF THE RUDMOSE AUTOMATIC AUDIOMETER.

Fig. 5. REAR VIEW OF A SUBJECT BEING GIVEN AN AUDITORY THRESHOLD TEST IN A SOUND ATTENUATION BOOTH.

Protection from Blast

For protection from the shower of unburned propellent particles at the 4 psi pressure position, the subjects wore Face Protectors, FSN-D8415-243-9844 (Fig. 6, 7). Because the unburned powder particles continued to hit the subjects' faces through the eye holes of the Face Protectors, the M9A1 Gas Mask was obtained for use by the subjects and the firing site monitors during the 6 and 8 psi exposures. The canisters were removed from the M9A1 in accordance with current practice for use of the gas mask as a face protector (Fig. 8, 9, 10). The subjects' positions for the 8 psi exposures and all of the monitors' positions were not in normal crew areas.

The firing site monitors reported that their chest cavities ached after exposure to 80 impulses at approximately 5 psi, in one day. To provide body protection for the subjects and the firing site monitors, blast protection aprons were worn. During the 6 and 8 psi exposures of the subjects, the firing site monitors used the aprons because they were exposed to approximately 8 psi peak overpressures. The subjects wore the aprons during exposure to 8 psi. The aprons consisted of three-foot squares of four-inch-thick foam rubber, curved to form an approximately 270-degree layer around the wearer (Fig. 8, 9, 10).

Steel helmets with liners were worn during all exposures.

Fig. 6. REAR RIGHT VIEW OF A SUBJECT WEARING THE PROTECTIVE FACE MASK AS SEEN FROM THE SOURCE OF THE 4.5 psi IMPULSE.

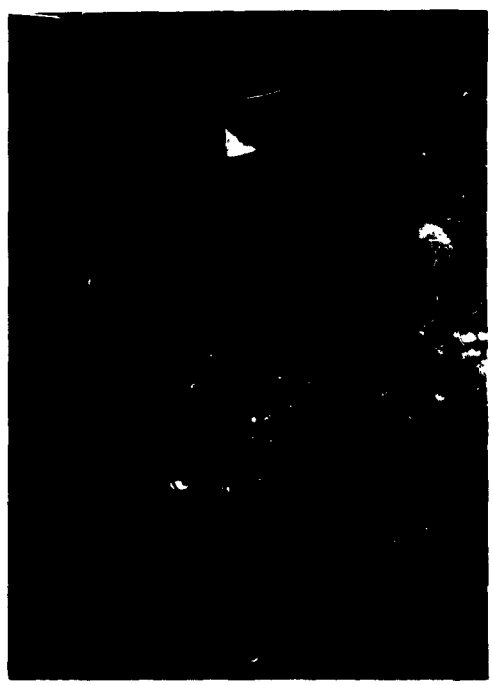

Fig. 7. REAR LEFT VIEW OF A SUBJECT WEARING PROTECTIVE CLOTHING FOR EXPOSURE TO 7.2 psi.

Fig. 8. REAR LEFT VIEW OF A SUBJECT WEARING PROTECTIVE CLOTHING FOR EXPOSURE TO 7.2 psi.

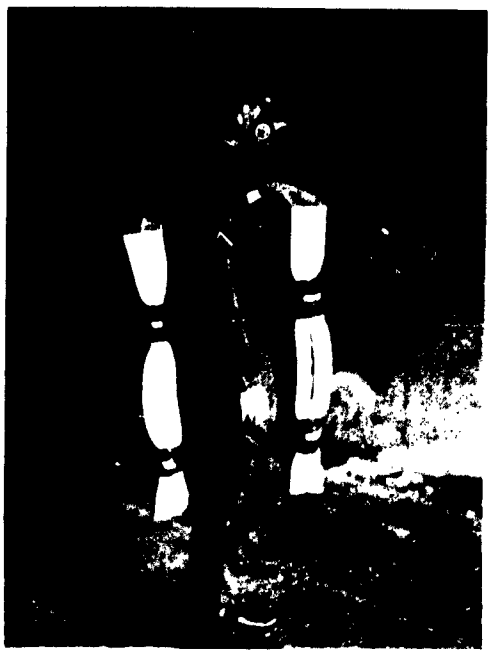

Fig. 9. RIGHT SIDE VIEW OF A SUBJECT WEARING PROTECTIVE CLOTHING FOR EXPOSURE TO 7.2 psi.

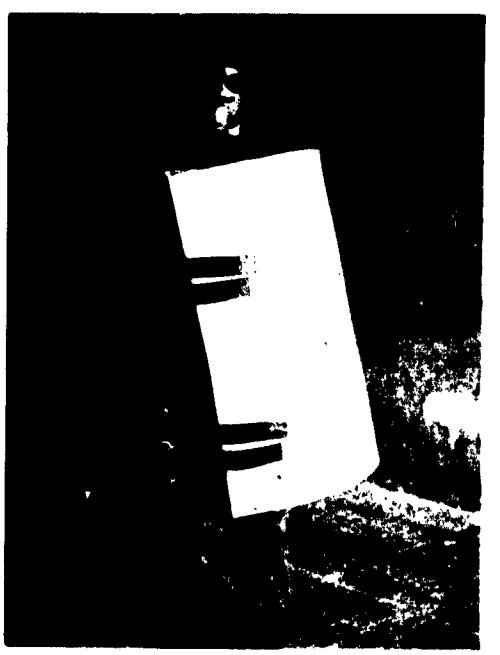

Fig. 10. FRONT VIEW OF A SUBJECT WEARING PROTECTIVE CLOTHING FOR EXPOSURE TO 7.2 psi.

CONTROLS

All pre- and post-firing audiograms for each man were conducted on the same audiometer.

Identical sound-reverberation-controlled vans were used at the firing site and the barracks area for the pre- and post-firing audiograms, and the two- and four-hour follow-up audiograms.

The effects of incidental loud noises were controlled by requiring the subjects to wear MSA Noisefoe over-the-ear protectors when they were in the vicinity of the firing range.

The effects of weather conditions were kept to a minimum by exposing all subjects for each pressure level during the same day. Weather variation effects associated with the different pressure-level treatments were minimized by avoiding extreme conditions such as rain, high wind, and fog.

Each subject maintained his lateral and vertical head position by aligning with two reference poles. His radial position about the muzzle, relative to the gun's axis, was determined by a locating stake above which the subject oriented himself. A monitor remained with each subject during the test exposure to insure that he kept his head in the proper location.

The rate of fire was reproduced from condition to condition by instructing the gun crew to fire at their maximum rate (approximately three seconds per round).

To maintain a similar gun tube temperature for all firings, two rounds were fired prior to each test series and whenever there was a delay of more than one hour.

Each subject was given at least five practice audiograms to familiarize him with the proper method of taking an audiogram with the Rudmose Automatic Audiometer, Model ARJ-4. The Rudmose Automatic Audiometer was then used for all pre- and post-exposure audiograms.

PROCEDURE

Subjects were brought to the test area in groups of four to facilitate rapid movement of the test schedule. They wore MSA Noisefoes at all times en route to, from, and while in the vicinity of the firing site; except when actually being tested for threshold hearing acuity or being exposed to the impulse noise. Though the subjects were in the vicinity of the howitzer emplacement, they were kept as far from it as feasible. The impulse noises were audible, but the sound pressure level was negligible (less than 0.1 psi).

Subjects were exposed to the selected pressures in pairs, one on each side of the gun. Subjects wore ear plugs in both ears so the untested ear would also be protected. The subjects were always tested first to establish their hearing threshold, then exposed to the pressures, then retested on the same ear; the two subjects constituting a pair stayed together throughout the study.

Immediately before each exposure, the auditory threshold for the test ear of each subject was determined by an air-conduction audiogram.

Part One

This part of the study simulated field conditions in that the subjects were instructed in the proper method of inserting the ear plugs but were not supervised while inserting them. They were exposed to sound pressure levels of 2, 4, and 6 psi, which closely approximate the levels experienced by gun crews. Twelve of the subjects were exposed to five rounds of rapid fire, and ten of the subjects were exposed to ten rounds. They were dressed for normal field conditions at 1.8 and 4.5 psi, but they wore face protectors for the 6 psi level to deflect the spray of unburned powder.

Odd-numbered pairs of subjects -- first, third, fifth, etc. -- received five rounds of impulses, and even-numbered pairs -- second, fourth, sixth, etc. -- received ten rounds of impulses.

The three pressure level exposures were conducted at approximate weekly intervals. Each subject's full recovery from the previous TTS was verified before each exposure by comparing the threshold level of each pre-firing audiogram with his previous pre-firing audiogram.

The pre-firing audiogram measured each subject's threshold for the following:

2000 cps for the first 120 seconds (0-2 minutes)

4000 cps for the 2 - 3 minute period

500 cps for the 3.0 - 3.5 minute period

1000 cps for the 3.5 - 4.0 minute period

2000 cps for the 4.0 - 4.5 minute period

3000 cps for the 4.5 - 5.0 minute period

4000 cps for the 5.0 - 5.5 minute period

6000 cps for the 5.5 - 6.0 minute period

At the time of the last impulse noise, the audiometers' 2000 cps test signals were started. This insured that the 4000 cps test tone would start exactly two minutes after the last impulse noise. The subjects returned from their firing positions immediately, and their 2000 cps hearing thresholds were being retested within 90 seconds after the final impulse. This allowed at least one-half minute for testing the 2000 cps threshold. The 4000, 500, 1000, 2000 cps, etc., post-firing audiogram testing order was identical to the pre-firing audiogram.

Additional post-firing audiograms were administered two and four hours after exposure. If a subject had not recovered from a TTS by the four-hour post-firing audiogram, he was tested at 24 hours after exposure and at 48-hour intervals thereafter until complete recovery was noted. Starting with the two-hour post-firing audiograms, both ears of each subject were tested at each frequency for 30-second periods (the normal Rudmose Automatic Audiometer test).

Part Two

This second part of the study differed from field conditions in several ways: the subjects were nearer the muzzle than the normal gun crew positions; they wore more body protection than normal; they used a reference sound to assure a proper fit of the ear plugs; and they did not move between the time the V-51R was inserted and the time the first

impulse was delivered. This last precaution was required because of the possibility that ear plugs might become loose after vigorous head movements. Procedures described in Appendix B were followed as closely as possible.

The subjects on the right side of the gun were exposed to 8 psi after they had verified that the V-51R was inserted to achieve the best sound attenuation. The men in this group wore four-inch-thick foam rubber aprons, to protect their torsos from blast pressure, and face masks to provide protection from the shower of unburned propellent (Fig. 8).

The subjects on the left side of the gun were exposed to 1.4 psi with no ear protection in the test ear and plugs in the non-test ear. The same order of exposures was employed as in Part One.

Pre- and post-firing audiograms were administered in the same manner and at the same time intervals as in Part One.

RESULTS

In the first paired columns of Table 1, the effects of a single 2 psi round on an ear-plug-protected ear can be compared in terms of the auditory thresholds of the subjects at 4000 cps immediately prior to and two minutes after exposure. The histograms of these data are given in Figure 11.

Part One

The 4000 cps pre-firing audiogram thresholds and the two-minutes-after-impulse TTSs for each subject are shown in the second, third, and fourth pairs of columns of Table 1 for the 2, 4, and 6 psi impulse exposures. The histograms for these data are given in Figure 12. Note that the base reading (the first column of each pair) is not constant for an individual from day to day. This may be attributed to one or all

TABLE 1

Pre-firing Audiogram and Post-firing Audiogram TTS Data for the 4000 cps Frequency

SUB-JECT	*2psi 28 Sep PRE-TEST	2 MIN TTS	2psi 2 Oct PRE-TEST	2 MIN TTS	4psi 5 Oct PRE-TEST	2 MIN TTS	6psi 12 Oct PRE-TEST	2 MIN TTS	8psi 22 Oct PRE-TEST	2 MIN TTS	1.5psi 22 Oct PRE-TEST	2 MIN TTS	FINAL TEST	FINAL DATE (Oct)
							- - - - - 5 Rounds - - - - -							
AL	5	5	15	0	0	10	5	5	0	0	—	—	5	23
BR	-5	0	- 5	0	-5	0	-5	5	—	—	-5	5	-5	22
EL	25	—	25	0	25	(——Small V5IR Ear Plug Did Not Fit——)							25	12
FR	5	0	20	5	20	0	25	(——Late TTS Recovery——)					15	17
IL	15	-5	10	5	20	10	20	5	15	20	—	—	20	24
JR	-5	0	—	—	-10	5	-5	10	—	—	-5	0	-5	22
ML	0	25	-5	10	0	25	5	5	0	0	—	—	-5	22
NR	10	0	15	5	15	0	10	0	—	—	15	45	15	24
QL	0	—	0	0	-5	15	0	5	—	—	—	—	0	23
RR	-10	20	—	—	-5	0	—	—	—	—	0	0	-10	22
UL	15	-5	0	0	-5	0	10	-5	5	0	—	—	0	22
VR	-5	—	-15	0	-20	5	0	0	—	—	-5	65	-5	29
							- - - - - 10 Rounds - - - - -							
CL	5	0	0	5	5	0	5	5	5	0	—	—	5	22
DR	0	0	-5	0	-5	0	-5	0	—	—	-5	0**	-5	23
GL	5	5	5	5	5	0	—	—	5	0	—	—	-5	22
HR	-5	—	-5	0	-5	0	0	0	—	—	-5	15**	-5	23
KL	5	0	5	0	5	0	0	5	-5	0	—	—	-5	22
LR	5	0	5	0	10	—	5	0	—	—	10	55	10	24
OL	0	10	-5	5	5	0	5	0	0	0	—	—	0	22
PR	5	0	10	0	10	-5	10	0	—	—	5	50	5	24
SL	5	-10	5	0	10	0	10	0	10	10	—	—	15	23
TR	-10	10	-10	0	-10	—	-5	70***	(——Ear Drum Ruptured——)				-10	17

*Single-round exposure. **Two-round exposure. ***Five-minute TTS.

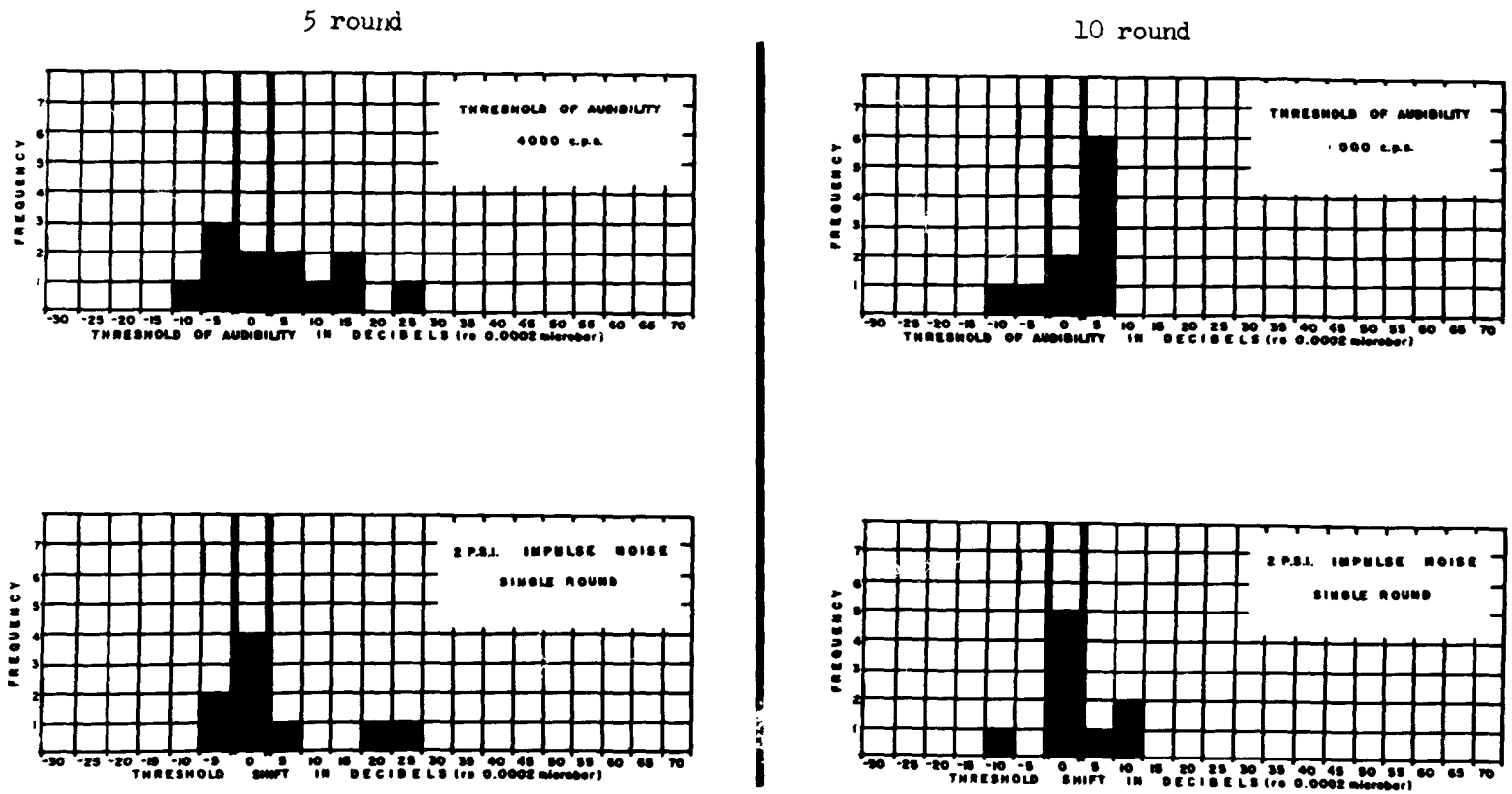

Fig. 11. HISTOGRAMS OF THE INITIAL THRESHOLDS AND THE SINGLE ROUND TTS FOR THE 5- AND 10-ROUND TREATMENT GROUPS.

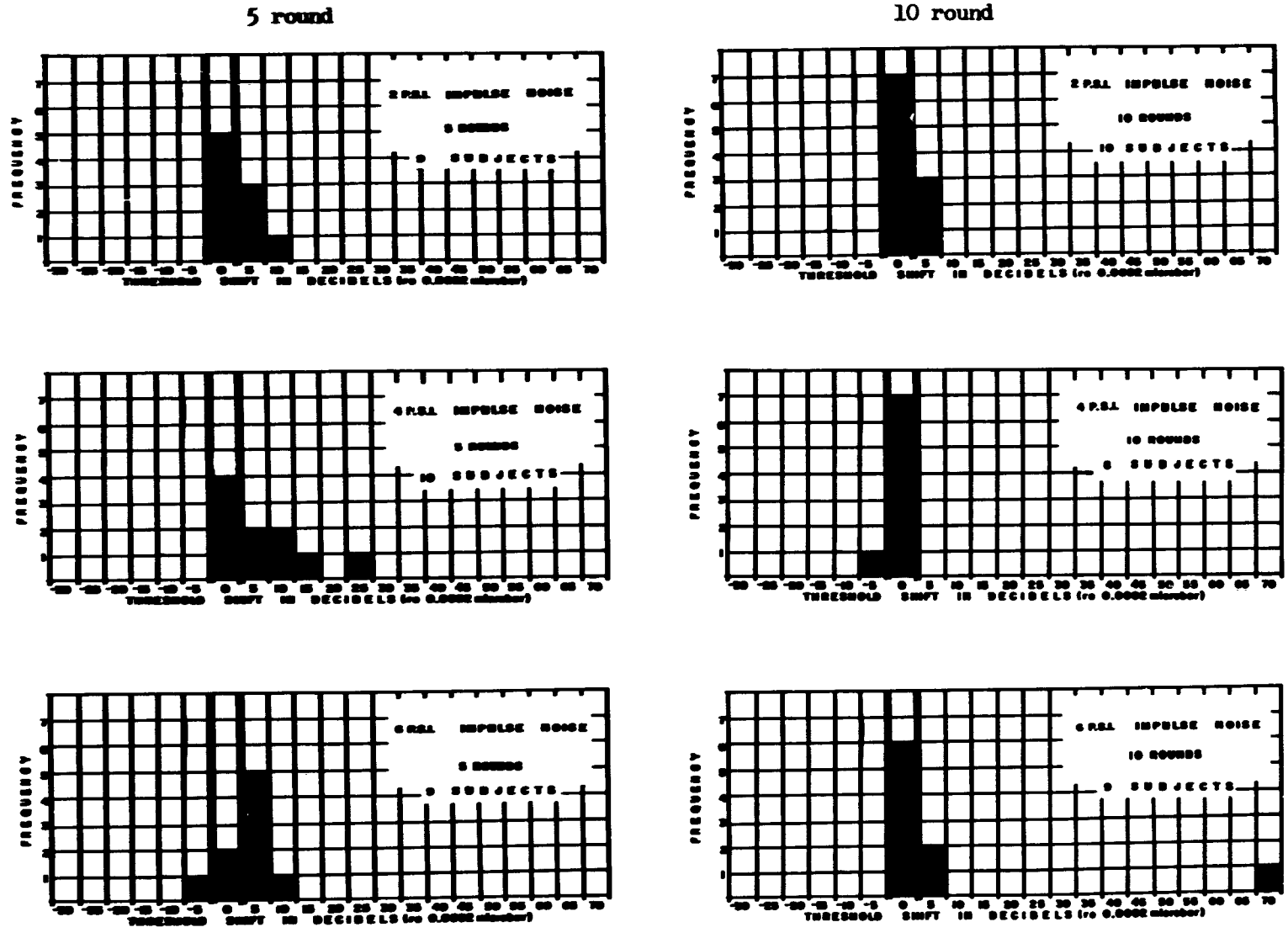

Fig. 12. HISTOGRAMS OF THE TTS FOR THE 5- AND 10-ROUND TREATMENT GROUPS UNDER 2, 4, AND 6 psi IMPULSE NOISE CONDITIONS.

of the following causes: the audiometers are calibrated to be reliable within ±3 dB from one test to another; the day-to-day variations within the subjects; or unavoidable background noise. If no score is given for a subject at a particular test time, it is because the trace was erratic and could not be read accurately.

Five points are particularly notable in Table 1 and Figure 12. First, the single-round exposures produced greater mean shifts than the 5- and 10-round exposures. This result may be due to the trauma of the first exposure to high impulse pressure. Second, subject EL shows an initial threshold of 25 dB at 4 kc. Before 28 September 1962, he met the selection criteria (15 dB or less at 4 kc). It is probable that psychological factors caused the apparent discrepancy between selection criteria and his pre-firing audiogram. Third, subject EL was dropped prior to the 4 psi exposure because the small V-51R Ear Plug would not stay in his ear canal. Fourth, subject FR failed to recover to the pre-firing audiogram threshold level which he had prior to the single-round 2 psi exposure. He was inadvertently exposed to the 4 psi impulses and was then dropped from the study. Fifth, subject TR incurred a loss of 70 dB during the 6 psi exposure. He reported sharp pains when exposed to the first and second impulses and it was found that his eardrum had ruptured. The writers and the subject believe that the ear plug was not properly placed prior to his exposure — a situation which is very likely to occur during the stress of combat operations. Subject TR recovered from his eardrum rupture and all subjects recovered from their TTSs before they were released.

The results discussed above are based on the 4000 cps data. The 2000 cps data appeared less significant but are included in Appendix C.

Part Two

The fifth and sixth paired columns of Table 1 give the pre-firing audiogram thresholds and the TTSs for the 8 and 1.5 psi exposures at the 4000-cps frequency. The histograms for these data are shown in Figure 13. Note that the 1.5 psi treatment (exposures with no ear protection) is above the maximum tolerable pressure for more than 30 percent of the subjects exposed to their full schedule of rounds; that is, two subjects of the seven incurred TTSs greater than 50 dB. In addition, two of the

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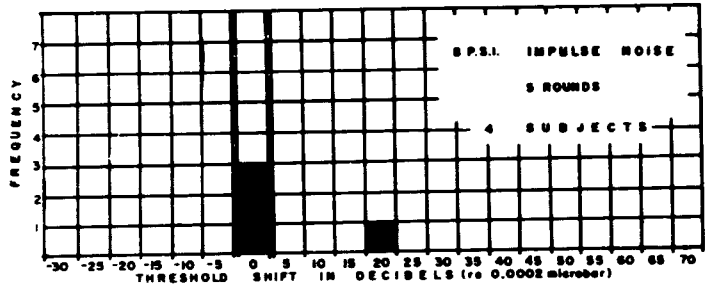

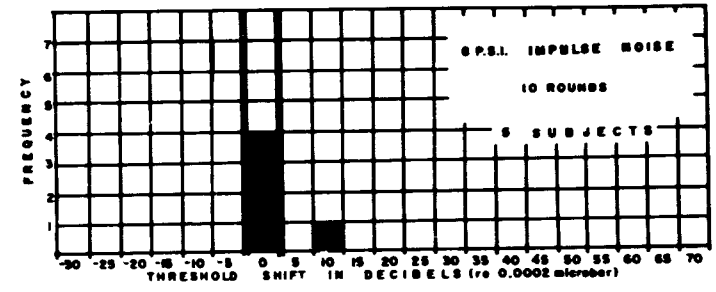

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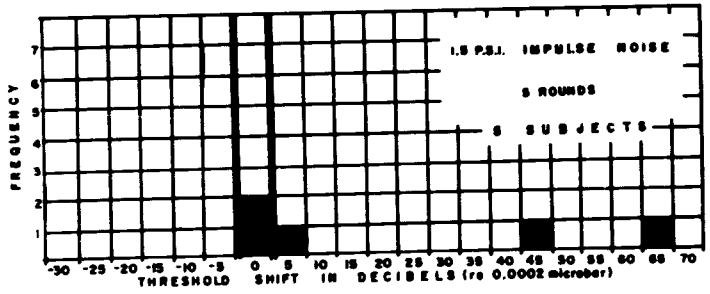

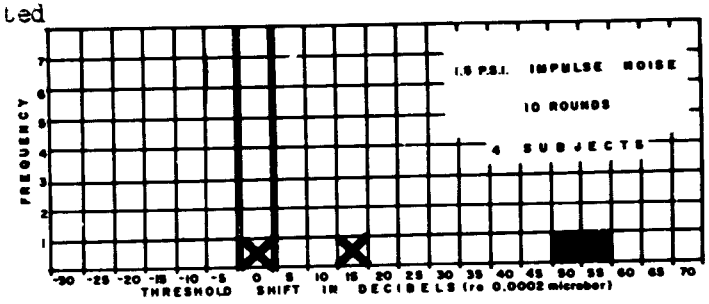

Fig. 13. HISTOGRAMS OF THE TTS FOR THE 5- AND 10—ROUND TREATMENT GROUPS UNDER 8 psi PROTECTED AND 1.5 psi UNPROTECTED CONDITIONS. (The X is used to designate subjects who only stayed for two rounds of exposure.)

subjects said they were too uncomfortable to remain in their positions after only two rounds of the ten they were scheduled to receive. Further, the 45- and 50-dB TTSs should be considered as exceeding the safe limit for extended repetition of the impulse noises being considered in this study.

It should be noted that the 8 psi impulse treatment with ear plug protection was markedly less severe than the 1.5 psi treatment without protection. Had time permitted further study of these subjects, a larger sampling of the two conditions in this part of the study would have been obtained by exposing each group to the other condition; that is, the group of subjects exposed to 1.5 psi (but not the two subjects whose TTSs exceeded the drop-out criterion) would have been exposed to 8 psi with ear plug protection, and the group exposed to 8 psi would have been exposed to 1.5 psi without ear plug protection.

DISCUSSION AND CONCLUSIONS

Fitting Plugs

The V-51R Ear Plugs were fitted by a physician at the U. S. Army Hospital after any accumulations of wax had been removed from the subjects' ears. One of the 22 subjects was dropped during the study because the "small"-size ear plug kept popping out of his ear canal. This subject was fitted again and, although the originally fitted plugs would stay in his ear canal at the hospital, the subject could not get them to stay in at the firing site. Since the "extra small" size was not available and the open ear exposure of the subject to the blast would very likely have caused a permanent hearing loss, the subject could not be retained.

Blast Exposures

Exposures to the peak overpressures during the simulated-field-operations portion of this study were made at 2, 4, and 6 psi with the subjects' ears directed toward the sound source (the muzzle brake exhaust). Although this was selected as the worst condition and all of the test ears were identically positioned, no consideration was given to some other possible field situations; for example, the ear plug might become dislodged during vigorous head, jaw, or upper torso motions which occur while assembling, carrying, and loading of the rounds. The actual exposure rate might well exceed the ten rounds

at three-second intervals which were evaluated in this study.

In spite of the fact that a subjects' only responsibilities were to see that his ear plug was inserted and that his ear was in the designated position during the blast exposures, one man's ear plug was so loosely inserted that he suffered a perforated eardrum, severe tinnitus, and a temporary hearing threshold shift of 70 dB (measured two minutes after a ten-round exposure). This man could not be retained as a subject for the second part of the study, although he did recover from his TTS.

Hearing Loss

The second part of the study demonstrated that exposure to 8 psi peak overpressure while wearing properly fitted ear plugs was much less likely to cause a hearing loss than exposure to a 1.5 psi peak overpressure without ear protection. These pressures correspond to the maximum peak overpressure which the chief of section of the 105mm Howitzer XM103 (positioned immediately behind and outside of the right wheel) is subjected to during firing at 100 percent rated maximum tube pressures. He is exposed to 1.5 psi when no muzzle brake is used and to 8 psi when the WTV-F8241 (high efficiency) muzzle brake is used. For all of the nine men exposed to as much as 8 psi peak overpressure under controlled conditions, the V-51R Ear Plug afforded better than the equivalent of 20 dB noise level attenuation (the difference between 1.5 and 8 psi). At least four of the nine men exposed to 1.5 psi without protection could be expected to suffer permanent hearing losses if regularly exposed to this condition (8).

Other Pathological Effects

Besides the risk of hearing loss, blast from the muzzle brake can have other dangerous effects, including such things as: ruptures in the exposed skin surfaces from showers of unburned propellent particles; nose and eye irritations from the exhaust gases; and nose and chest pains due to the impact of the wave front. All concerned felt it was necessary to use face protectors at pressures above 4 psi and four-inch-thick foam rubber aprons at pressures above 6 psi, to reduce these adverse effects on the subjects.

Peak Overpressure and Number-of-Rounds Treatment

With protected ear exposures, there were no systematic TTS differences that could be attributed to either peak overpressure (2 to 8 psi) or number of rounds (five or ten). This result is attributed to the large degree of protection afforded by ear plugs that fit properly.

Selection of Subjects

For safety and experimental control considerations, the 32 subjects available for this study were reduced by five for medical reasons (history of ear and sinus infections) and by another five to eliminate those subjects with hearing losses at 2000 to 4000 cps (hearing threshold acuities worse than 15 dB).

It is difficult to say how the experimental group's characteristics were affected by rejecting the five men who showed hearing losses. If middle ear pathology had produced these losses, the men might have been less sensitive to damage because the middle ear would, in effect, tend to "insulate" the cochlea from strong stimulation. But if these men were cases of so-called nerve loss, they might have been more sensitive to further damage.

SUMMARY

Before generalizing from the findings of this study, the sources of experimental errors must be considered. They include the random sampling errors introduced by using a small number of subjects, as well as systematic errors introduced by the selection process, which may have made the group less sensitive to hearing losses. The net effect was probably that a normal U. S. Army population may be even more susceptible to losses.

Results of the study indicate these conclusions:

a. The peak overpressures at the crew positions of the XM102 are high enough to damage an unprotected ear permanently.

b. When properly fitted* to healthy men** and properly inserted*** by each man, the Army-issue, noise-protection ear plugs will protect personnel against hearing-acuity losses at all crew positions of the XM102 with any of the three efficiency muzzle brakes.

RECOMMENDATION

It is recommended that the pathological effects of 4 - 8 psi peak overpressures on man should be studied further, including at least the effects on chest, nose, and sinuses, under field conditions to determine the limits of human endurance.

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* "Properly fitted" requires that the correct size is chosen for each ear, and that men who cannot be fitted with available sizes must be rejected.

** "Healthy man" is one who has no chronic or acute ear or sinus infection, and no accumulations of ear wax.

*** "Properly inserted by each man" requires that each man must:

(1) Train to obtain a fit that will result in the maximum attenuation of a reference sound source.

(2) Obtain sufficient experience to develop a feeling for the length of his ear canal and what a good fitting seal feels like.

REFERENCES

1. American Standards Association, Inc. American Standard Criterion for Background Noise in Audiometer Rooms. New York: 1960.

2. Cohen, A. Temporary Hearing Losses for Protected and Unprotected Ears as a Function of Exposure Time to Continuous and Impulse Noise. Quartermaster Research & Engr. Center, TR-EP-151, Natick, Mass., 1961.

3. Fletcher, J. L. Comparison of Attenuation Characteristics of the Acoustic Reflex and the V-51R Ear Plug. U. S. Army Medical Research Laboratory Report No. 397, Ft. Knox, Ky.

4. Fletcher, J. L. & Silver, C. A. Attenuation Characteristics of Four Ear Protective Devices. U. S. Army Medical Research Laboratory Report No. 322, Ft. Knox, Ky., 1957.

5. Holland, H. H. Muzzle Blast Measurements on Howitzer, 105mm, M1A2E3 with Muzzle Brake No. 8. U. S. Army Engineering Laboratories Technical Memorandum 12-60, Aug. 1960, Aberdeen Proving Ground, Md.

6. Holland, H. H. Muzzle Blast Measurements on Howitzer, 155mm, M1A2E3 with Muzzle Brake No. 8. U. S. Army Engineering Laboratories Technical Memorandum 14-61, Jul. 1961, Aberdeen Proving Ground, Md.

7. Loeb, M. Comparison of Attenuation of Three Helmets and a Pair of Muffs by the Threshold Shift Method. U. S. Army Medical Research Laboratory Report No. 429, Ft. Knox, Ky., 1960.

8. Murray, N. E. & Reid, G. Experimental Observations on the Aural Effects of Gun Blast. Medical J. of Australia, 1946, 1, 611-617.

9. Neff, W. D. Hearing Losses and Protective Measures. In Benox Report, An Exploratory Study of the Biological Effects of Noise. Chicago: University of Chicago, 1953.

10. Psycho-Acoustic Laboratory, Harvard University. The Development of Ear Wardens Type V-51R, OSRD 5122, Cambridge, Mass., 1945.

11. Smith, M. G. A Pilot Study of Temporary Threshold Shifts Resulting from Exposure to High-Intensity Impulse Noise. U. S. Army Engineering Laboratories Technical Memorandum 19-61, Sep. 1961, Aberdeen Proving Ground, Md.

12. U. S. Army Medical Research Laboratory Project No. 26. Investigation of Ear Plugs for Protection Against Blast. Ft. Knox, Ky., 1944.

13. White, C. S. Biological Blast Effects, TID-5564, Lovelace Foundation, Albuquerque, N. M., 1959.

APPENDIX A

MUZZLE BRAKE BLAST PRESSURES

FROM 105mm HOWITZER

Analytical Laboratory Report 62-AL-188
12 October 1962

Title: Evaluation of Muzzle Blast Pressures from 105-MM Howitzer, M2A2E2 w/Muzzle Brake No. 8 for V51 Ear Warden Test

OMS No.: 5010.11.844

Prepared for: Arty Div, Arty Wpn Br, Field and AA Arty Sect

INTRODUCTION

Firings were conducted during September 1962, to evaluate the blast pressure from the muzzle of a 105-MM Howitzer, M2A2E2 with a No. 8 muzzle brake. This test was designed to provide distances along a line 150° right traverse from the line of fire where peak overpressures of 2, 4, 6, 8 and 10 psi would occur. Data obtained from a previous test (Muzzle Blast Measurements on HOWITZER, 105-MM, M2A2E2 w/Muzzle Brake No. 8; Howard H. Holland, Jr., Aug 1960) were plotted and the positions that indicated these pressure levels were noted. These positions provided the locations for the pencil-type, piezoelectric blast gages for this test.

INSTRUMENTATION

Ten piezoelectric, pencil-type blast gages were used to measure the shock front profile of the muzzle blast as it arrived at each position. Locations of these gages are presented in Inclosure 1.

The electrical outputs of the piezoelectric crystals in the blast gages were amplified and fed into an oscilloscope. Shutterless, high speed 35-mm movie cameras were used to photograph the beam deflections on the oscilloscope resulting from pressure variations sensed by the blast gages. In this manner a pressure history of the shock front at each gage location was recorded.

Gage Calibration

The blast gages used during this test were calibrated at the estimated pressure level each gage would be subjected to during the test. Calibrations were made by subjecting the gages to blast pressures resulting from detonating a one-pound bare charge of spherical pentolite. Each gage was exposed to three before-fire and two after-fire calibration shots.

The velocity of the shock front at each gage position during the calibration shot was determined from the arrival time of the shock wave at two velocity pick-up gages that spanned three feet. (The blast gage to be calibrated was positioned midway between the velocity pick-up gages.)

From the Rankine-Hugonoit equation which follows, the peak overpressure in the shock front was derived for each blast gage location.

$$P_v = \left[\frac{2\gamma}{\gamma+1}\right] P_o \left[\left(\frac{V \pm K}{C}\right)^2 - 1\right]$$ where:

P_v = Peak overpressure, psi
γ = Ratio of the specific heats of air (1.4)
V = Shock front velocity, fps
K = Wind correction factor, fps
C = Velocity of sound at local ambient temperature, fps
P_o = Local barometric pressure, psi

A gage constant (K_a) was established for each gage by relating P_v, the deflection of the pressure trace during each calibration shot, and the deflection corresponding to a known electrical charge. These are related in the following manner:

$$K_a = \frac{CVD_p}{D_c P_v}$$ where:

K_a = pQ/step
C = Calibration Capacitance, pQ
V = Voltage, 0.1 volts/step
D_p = Peak pressure trace deflection, in.
D_c = Calibration trace deflection, in.
P_v = Peak pressure, psi

RESULTS

A tabular summary of muzzle blast pressure data (peak overpressure, impulse, and positive duration) are presented in Inclosure 2.

Inclosure 3 presents both a chart of peak overpressure as a function of muzzle distance based on data from the earlier muzzle blast test of the same weapon and a similar plot showing data obtained from the present test. Because 8 psi and 10 psi overpressure levels were not obtained in the present test, the curve has been extended to show the positions at which these levels would be expected. Positions 2 and 3 do not lie on the line because the gage locations were not on the 150° right traverse line.

There are several possible explanations for the fact that lower overpressure levels were attained in this test than in the previous test.

First, a different propellant was used during this test. Because of the burning characteristics of a propellant, higher or lower muzzle pressures may exist at the instant of muzzle exit of the projectile. Second, the projectile fired during the present test differed from the projectile used for the earlier test. The projectiles were approximately the same weight, but the configurations of the shell bases were different. Another possible cause may be the difference of the heights of the gages above the ground for corresponding positions during the two tests.

RECOMMENDATION

Since the 10 psi and 8 psi overpressure levels may be critical with respect to the human factor, further tests should be conducted to substantiate the locations of these pressure levels as indicated by the extrapolated (broken line) curve shown in Inclosure 3.

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3 Incl
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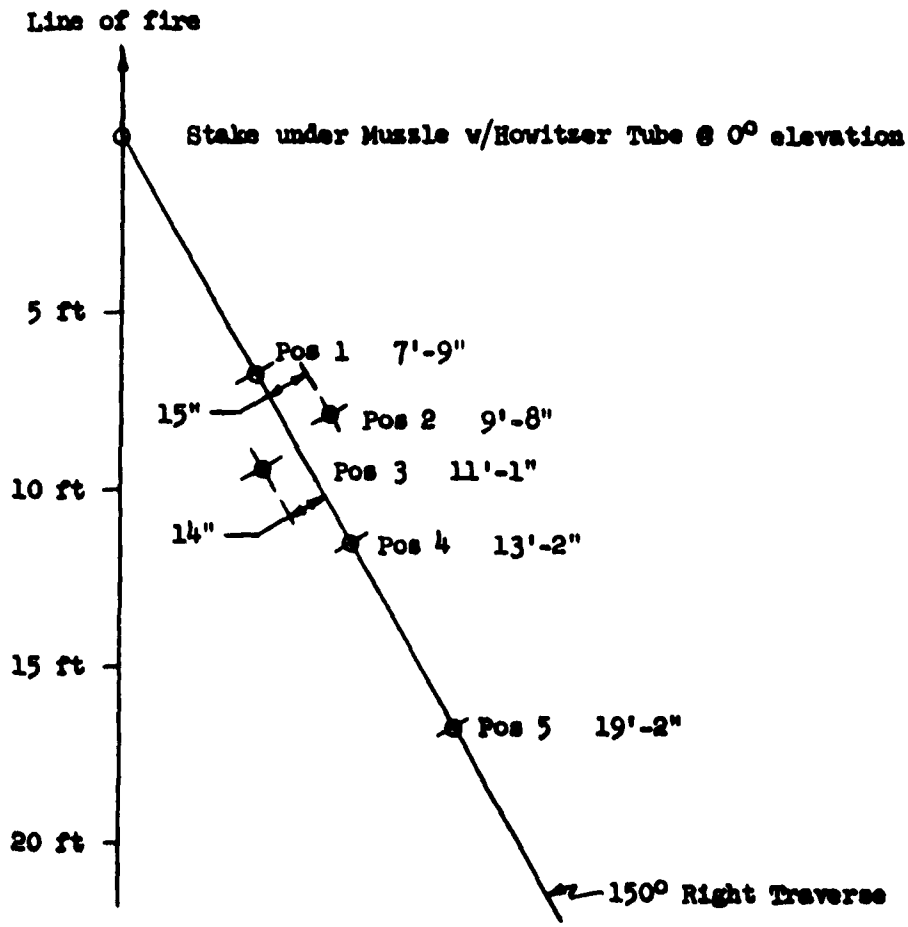
Location of Blast Gages for Muzzle Blast Evaluation
of 105-MM HOWITZER, M2A2E2 w/Muzzle Brake No. 8



Two gages were pointed at the muzzle at each position.

Inclosure 1

Anal Lab, Engr Labs, D&PS
Oct 62 CAS

Summary of Muzzle Blast Overpressure, Impulse and Positive Duration
For 105-MM HOWITZER, M2A2E2 with Muzzle Brake No. 8
Date Fired: 19, 20 September 1962

Weapon:
105-MM HOWITZER, M2A2E2, Ser No. 23249
105-MM TUBE, M2A2E2, Ser No. 56803

Ammunition:
Propellant: T36MP; Lot No.: RAD 64471; 0.042" web
Projectile: M1, Inert; Wt.: 28.4 ± 0.3 lb
w/M73 Dummy Fuze

Round Number	Gage Position No. 1						Gage Position No. 2						Gage Position No. 3					
	Gage No. 95			Gage No. 99			Gage No. 106			Gage No. 110			Gage No. 117			Gage No. 100		
	P	I	P.D.	P	I	P.D.	P	I	P.D.	P	I	P.D.	P	I	P.D.	P	I	P.D.
1	7.3	5.1	2.0	6.2	5.1	2.3	5.9	5.1	2.0	6.4	5.2	1.9	-	-	-	-	-	-
2	8.1	6.4	2.2	6.8	5.6	2.2	6.0	5.2	2.3	6.4	5.5	2.2	-	-	-	-	-	-
3	7.2	7.2	2.6	5.5	4.2	1.8	-	-	-	-	-	-	5.2	4.6	2.2	4.7	4.3	2.2
4	6.6	5.6	2.8	5.8	5.0	3.0	-	-	-	-	-	-	4.5	3.7	2.6	4.4	4.0	2.7
5	6.4	5.1	2.2	5.6	4.5	2.3	5.6	5.6	2.4	6.0	6.2	2.4	4.3	3.6	2.2	4.6	4.3	2.6
6	6.3	5.1	2.2	5.3	4.4	2.2	5.3	5.0	2.2	5.7	6.1	2.6	4.1	3.9	2.8	4.1	4.1	2.8
7	6.6	5.4	2.4	5.8	4.6	2.7	5.9	5.1	2.3	6.3	6.5	2.4	4.3	4.0	2.5	4.7	4.3	2.8
8	6.8	5.5	2.2	5.8	4.9	2.4	5.9	5.3	2.5	6.0	6.2	2.6	4.5	4.0	2.7	4.5	4.3	2.6
9	6.6	5.3	2.3	5.4	4.6	2.6	5.9	4.7	2.4	6.3	6.1	2.4	4.6	3.6	2.4	4.7	3.9	2.6
10	6.7	5.7	2.1	6.1	4.8	2.1	6.3	4.8	2.5	6.0	5.4	2.4	4.3	4.3	2.6	4.3	4.3	2.8
Avg of Rd No. 3-10	6.6	5.6	2.4	5.7	4.6	2.4	5.7	5.1	2.4	6.0	6.1	2.5	4.5	4.0	2.5	4.5	4.2	2.6
Avg of Two Gages	6.2	5.1	2.4				5.8	5.6	2.4				4.5	4.1	2.6			

Note: Round No. 1 and 2 were omitted from the average because the gages were not located at the same position as Round No. 3-10.

P is Pressure, psi; I is Impulse, lb-ms/sq in; P.D. is Positive Duration, ms

Anal Lab, Engr Labs, D&PS
Oct 62 CAS

Inclosure 2

Summary of Muzzle Blast Overpressure, Impulse and Positive Duration (continued)

Weapon:
105-MM HOWITZER, M2A2E2, Ser No. 23249
105-MM TUBE, M2A2E2, Ser No. 56803

Ammunition:
Propellant: T36MP; Lot No.: RAD 64471; 0.042" web
Projectile: M1, Inert; Wt.: 28.4 0.3 lb
w/M73 Dummy Fuze

Round Number	Gage Position: No. 4, Gage No. 111 P	I	P.D.	No. 4, Gage No. 93 P	I	P.D.	No. 5, Gage No. 91 P	I	P.D.	No. 5, Gage No. 87 P	I	P.D.
1	3.4	3.5	3.2	3.3	3.4	3.1	1.7	2.1	3.4	2.1	2.7	3.5
2	3.4	3.7	3.2	3.2	3.7	3.1	1.8	2.4	3.4	2.1	3.0	3.5
3	3.3	3.4	2.9	3.1	3.4	3.2	1.7	4.5	6.7	2.1	5.7	6.6
4	3.3	3.4	2.8	3.4	3.6	3.0	1.8	2.0	3.2	2.0	2.7	3.2
5	3.2	4.0	3.0	3.1	3.5	2.9	-	-	-	-	-	-
6	3.5	3.2	2.8	3.5	4.2	2.9	-	-	-	-	-	-
7	3.2	3.8	3.1	3.0	3.4	3.0	-	-	-	-	-	-
8	3.3	4.0	3.0	3.3	3.3	3.0	-	-	-	-	-	-
9	-	-	-	-	-	-	1.5	3.4	5.9	1.8	3.0	5.7
10	-	-	-	-	-	-	1.5/ 2.5		7.1	1.8/ 2.9	4.8	6.9
Avg of Rd No. 3-10	3.3	3.6	2.9	3.3	3.6	3.0	1.6	3.8	5.7	1.9	4.0	5.6
Avg of Two Gages	3.3	3.6	3.0				1.8	3.9	5.6			

Note: Round No. 1 and 2 were omitted from the average because the gages were not located at the same position as Round No. 3-10.

P is Pressure, psi; I is Impulse, lb-ms/sq in.; P.D. is Positive Duration, ms

Anal Lab, Engr Labs, D&PS
Oct 62 CAS

Inclosure 2

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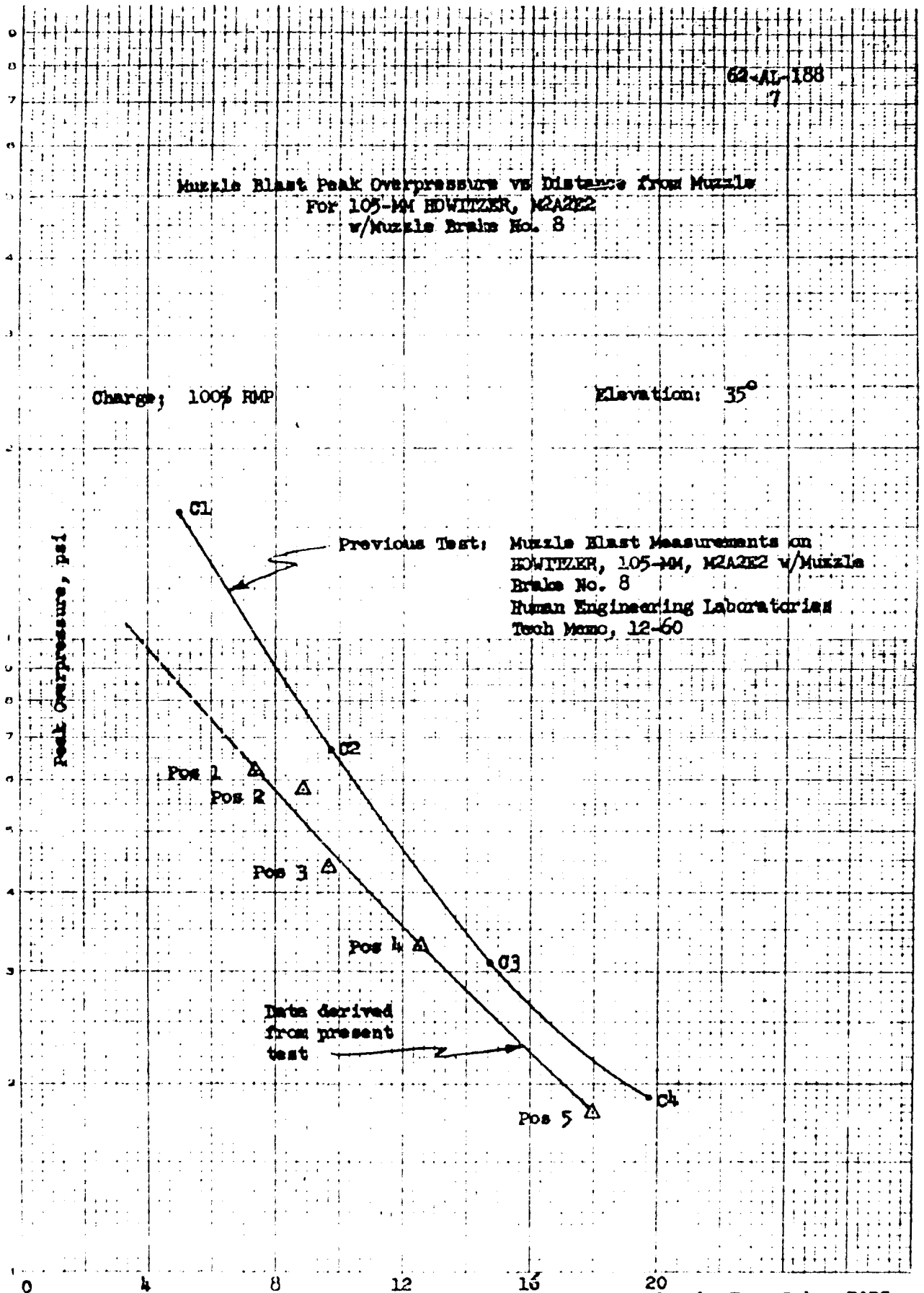

Anal Lab, Engr Labs, D&PS
Oct 62
CAS

Inclosure 3

Analytical Laboratory Report 62-AL-188A
(Covering Work from 22 Oct 62 to 29 Oct 62)
29 October 1962

Title: Supplement No. 1 to Analytical Laboratory Report 62-AL-188. Evaluation of Muzzle Blast Pressures from 105-MM HOWITZER, M2A2E2 w/Muzzle Brake No. 8 for V51 Ear Warden Test

OMS No.: 5010.11.844

Prepared for: Fld & AA Arty Sect, Arty Wpn Br, Arty Div

Data presented in this supplement were obtained from additional firings with the weapon used during the 16 September 1962 firings. Two piezoelectric, pencil type blast gages were positioned at each location shown on Chart 1 of this supplement to measure the shock front profile of each muzzle blast. One pair of gages was positioned on the 135° right traverse line and remained at this location throughout this phase of the test as a control. Another pair of gages was positioned by a member of the Human Engineering Laboratory as presented in the following table:

Location of Blast Gages During Test

Round Number	Distance from Muzzle to Gage, ft - in.
1 - 4	7 - 9
5 - 7	7 - 4
8	19 - 8
9	22 - 0
10, 11	20 - 9
12	7 - 7

Gages are positioned 60 inches above the ground, along the 150° right traverse line; except for Rd. 12 which was located 55" above ground along the 135° line.

Inclosure 1 presents a chart of the location of each pair of gages and the average peak overpressure measured at each location.

Inclosure 2 presents a round-by-round summary of the peak overpressure (psi), impulse (lb-ms/in.^{2}), and positive duration (ms).

Inclosure 3 presents a chart of the peak overpressures as a function of the gage distance from the muzzle for both phases of the test.

DISCUSSION

Data presented in this supplement substantiate the values derived from the firings of 16 September 1962 with the exception of the second position from the muzzle. Although this pressure is higher at this position than at the position nearer the muzzle it should be noted that the pressures at the reference position were also higher for this round.

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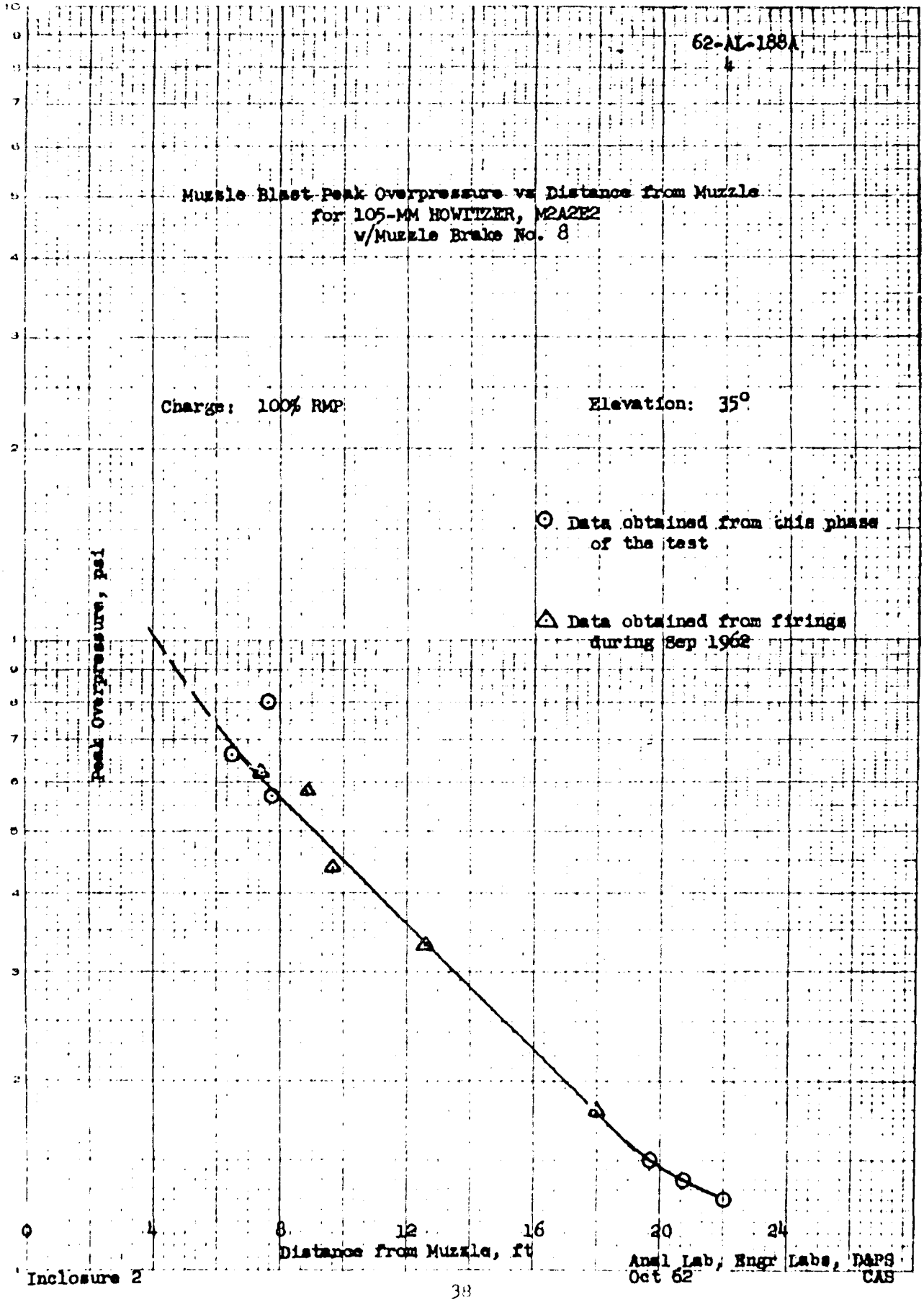
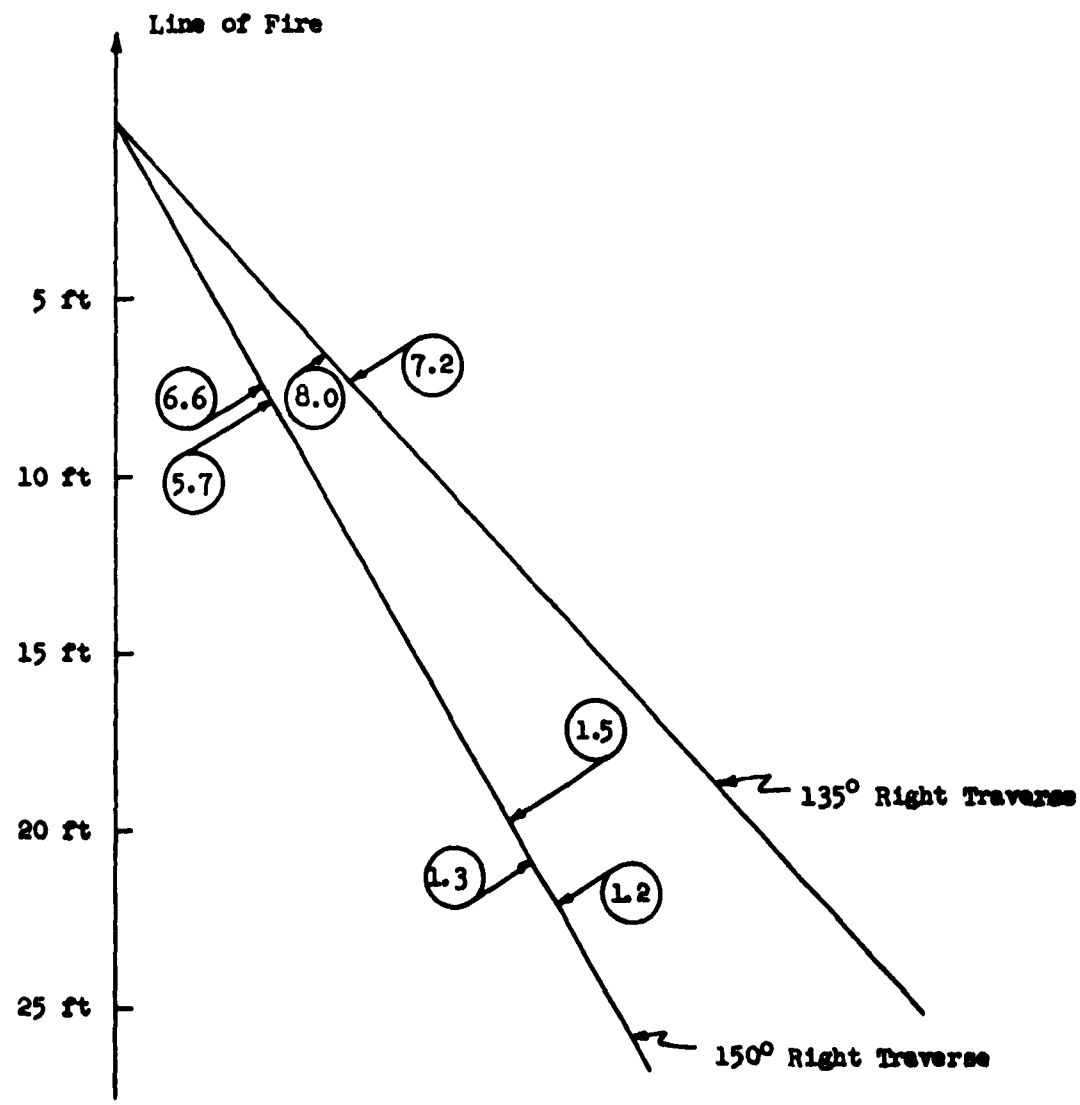


Inclosure 2

Anal Lab, Engr Labs, DAPG
Oct 62
CAS

Location of Blast Gages for Muzzle Blast Evaluation
of 105-MM HOWITZER, M2A2E2 w/Muzzle Brake No. 8



Two gages were pointed at muzzle at each position.

Summary of Muzzle Blast Overpressure, Impulse and Positive Duration For 105-MM HOWITZER, M2A2E2 with Muzzle Brake No. 8
Date Fired: 19, 20 September 1962

Weapon:
105-MM HOWITZER, M2A2E2, Ser No. 23249
105-MM TUBE, M2A2E2, Ser No. 56803

Ammunition:
Propellant: T36MP; Lot No.: RAD 64471; 0.042" web
Projectile: M1, Inert; Wt.: 28.4 ± 0.3 lb w/M73 Dummy Fuze

Round Number	Gage No. 95			Gage No. 99			Gage No. 106			Gage No. 110		
	P	I	P.D.	P	I	P.D.	P	I	P.D.	P	I	P.D.
	Position No. 1 (7' - 9")						Position No. 2 (7' - 3.5")					
1	5.3	4.8	2.6	6.1	5.1	2.7	8.2	6.4	2.4	8.1	5.9	2.4
2	6.0	5.6	2.8	6.5	5.3	2.7	7.1	6.1	2.2	6.7	5.9	2.3
3	5.3	5.1	2.9	5.9	5.1	2.6	8.3	6.4	2.0	8.1	6.0	2.0
4	5.0	5.2	2.8	5.5	5.2	2.9	7.5	6.8	2.1	6.9	6.2	2.1
Avg	5.4	5.2	2.8	6.0	5.2	2.8						
Avg of both gages	5.7	5.2	2.8									
	Position No. 3 (7' - 4")											
5	7.3	4.9	1.9	7.7	5.0	2.0	7.7	5.3	2.3	7.2	5.4	2.4
6	6.1	5.7	2.0	6.6	5.8	2.1	6.6	5.8	2.4	6.8	6.0	2.5
7	6.2	5.8	2.1	5.8	5.0	2.2	7.1	5.9	2.0	6.9	5.6	2.2
Avg	6.5	5.5	2.0	6.2	5.3	2.1						
Avg of both gages	6.6	5.4	2.0									
	Position No. 4 (19' - 8"											
8	1.5	2.1	3.2	1.5	1.9	3.2	6.6	6.3	2.1	6.2	5.5	2.0
Avg of both gages	1.5	2.0	3.2									
	Position No. 5 (22 - 0)											
9	1.2	2.7	6.6	1.2	2.7	6.3	5.4	6.1	2.2	6.7	5.8	2.3
Avg of both gages	1.2	2.7	6.4									
	Position No. 6 (20' - 9"											
10	1.3	3.0	7.2	1.3	3.0	6.9	7.0	5.8	2.4	7.4	5.9	2.4
11	1.3	3.0	6.8	1.4	3.2	6.7	7.0	5.6	2.0	7.2	5.6	2.0
Avg	1.3	3.0	7.0	1.4	3.1	6.8						
Avg of both gages	1.3	3.0	6.9									

Summary of Muzzle Blast Overpressure, Impulse and Positive Duration (Continued)

Weapon:
105-MM HOWITZER, M2A2E2, Ser No. 23249
105-MM TUBE, M2A2E2, Ser No. 56803

Ammunition:
Propellant: T36MP; Lot No.: RAD 64471; 0.042" web
Projectile: M1, Inert; Wt.: 28.4 ± 0.3 lb w/M73 Dummy Fuze

Round Number	Gage No. 95			Gage No. 99			Gage No. 106			Gage No. 110		
	P	I	P.D.	P	I	P.D.	P	I	P.D.	P	I	P.D.
	Position No. 7 (7' - 7")											
12	7.8	6.7	2.3	8.1	6.2	2.2	7.5	6.1	2.3	7.7	6.0	2.4
Avg of both gages	8.0	6.4	2.2									
Avg							7.2	6.1	2.2	7.1	5.8	2.2
Avg of both gages							7.2	6.0	2.2			

P is Pressure, psi; I is Impulse, lb-ms/sq in.; P.D. is Positve Duration, ms.

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APPENDIX B

Subparagraph 6.3 of paragraph 6, Test Procedures, of "American Standard Method for the Measurement of the Real-Ear Attenuation of Ear Protectors at Threshold":

6.3 Installation of Ear Protectors

6.3.1 Ear plugs shall be inserted or earmuffs shall be put on by the listener himself, while he is seated in the test chair and while in the presence of a noise whose energy per cycle is constant as a function of frequency and whose over-all sound pressure level at the listener's position is 70 to 80 dB above 0.002 microbar.

6.3.1.1 It shall be the responsibility of the experimenter in charge of the tests to see that the proper size of ear protector is selected for each listener and to indoctrinate each listener so that the ear protector is installed according to instructions from the manufacturer.

6.3.1.2 The listener shall also be instructed to manipulate the ear protectors until the noise appears to be nominal.

6.3.2 After the ear protector has been installed in such a way that the listener is satisfied that further manipulation of the ear protector would not further reduce the noise in loudness, he should be instructed to raise and lower the jaw by saying vigorously the sounds "ah" and "ee" alternately ten times and to turn his head from right to left ten times. He should be instructed to keep his mouth closed to avoid any further jaw and head movement and to refrain from touching the device, throughout the test.

APPENDIX C

2000 CYCLE PER SECOND DATA

TABLE 2

Preaudiogram and Postaudiogram TTS Data for the 2000 cps Frequency

SUBJ	*2psi 28 Sep PRE-TEST	2 MIN TTS	2psi 2 Oct PRE-TEST	2 MIN TTS	4psi 5 Oct PRE-TEST	2 MIN TTS	6psi 12 Oct PRE-TEST	2 MIN TTS	8psi 22 Oct PRE-TEST	2 MIN TTS	1.5psi 22 Oct PRE-TEST	2 MIN TTS	FINAL TEST	DATE (Oct)
							- - - - - 5 Rounds - - - - -							
AL	-10	-	20	5	0	-5	-10	5	-10	0			-10	22
BR	- 5	0	- 5	0	-10	5	- 5	0			-10	15	0	22
EL	5	-	0	10	5	(----Small V51R Ear Plug did not fit----)							5	2
FR	0	-5	20	10	0	0	5	(----Late TTS recovery-----)					5	12
IL	-10	0	-15	- 5	-10	5	- 5	- 5	-10	0			-10	22
JR	- 5	5	-10	5	-10	5	- 5	10			0	0	0	22
ML	0	35	- 5	0	0	30	-10	0	-10	5			-10	22
NR	- 5	0	0	5	- 5	0	-10	0			-10	35	- 5	22
QL	-10	10	- 5	0	- 5	10	5	0	-10	0			-10	22
RR	- 5	15	- 5	5	- 5	0	- 5	5			-10	15	-10	22
UL	- 5	- 5	-10	10	-10	0	- 5	0	-10	0			-10	22
VR	-10	-	-	-	-10	0	-10	10			-10	55	-10	23
							- - - - -10 Rounds - - - - -							
CL	- 5	0	-10	5	- 5	0	- 5	0	-10	5			- 5	22
DR	5	0	- 5	5	- 5	10	- 5	5			- 5	5**	- 5	22
GL	- 5	5	15	0	-15	0	-15	0	-10	0			-15	22
HR	-15	0	-15	0	-15	0	-15	10			-15	0**	-10	22
KL	5	10	5	0	- 5	5	- 5	5	5	10			- 5	22
LR	0	0	5	0	5	- 5	5	- 5			5	10	0	22
OL	-15	5	-10	0	-10	0	-15	0	- 5	0			-10	23
PR	-10	0	-10	5	-10	5	-10	5			-10	20	-10	22
SL	- 5	-	- 5	- 5	- 5	5	- 5	0	0	0			0	22
TR	-15	15	-	-	-20	10	-15	20	(---Ear drum ruptured---)				-20	14

*Single-round exposure. **Two-round exposure only.

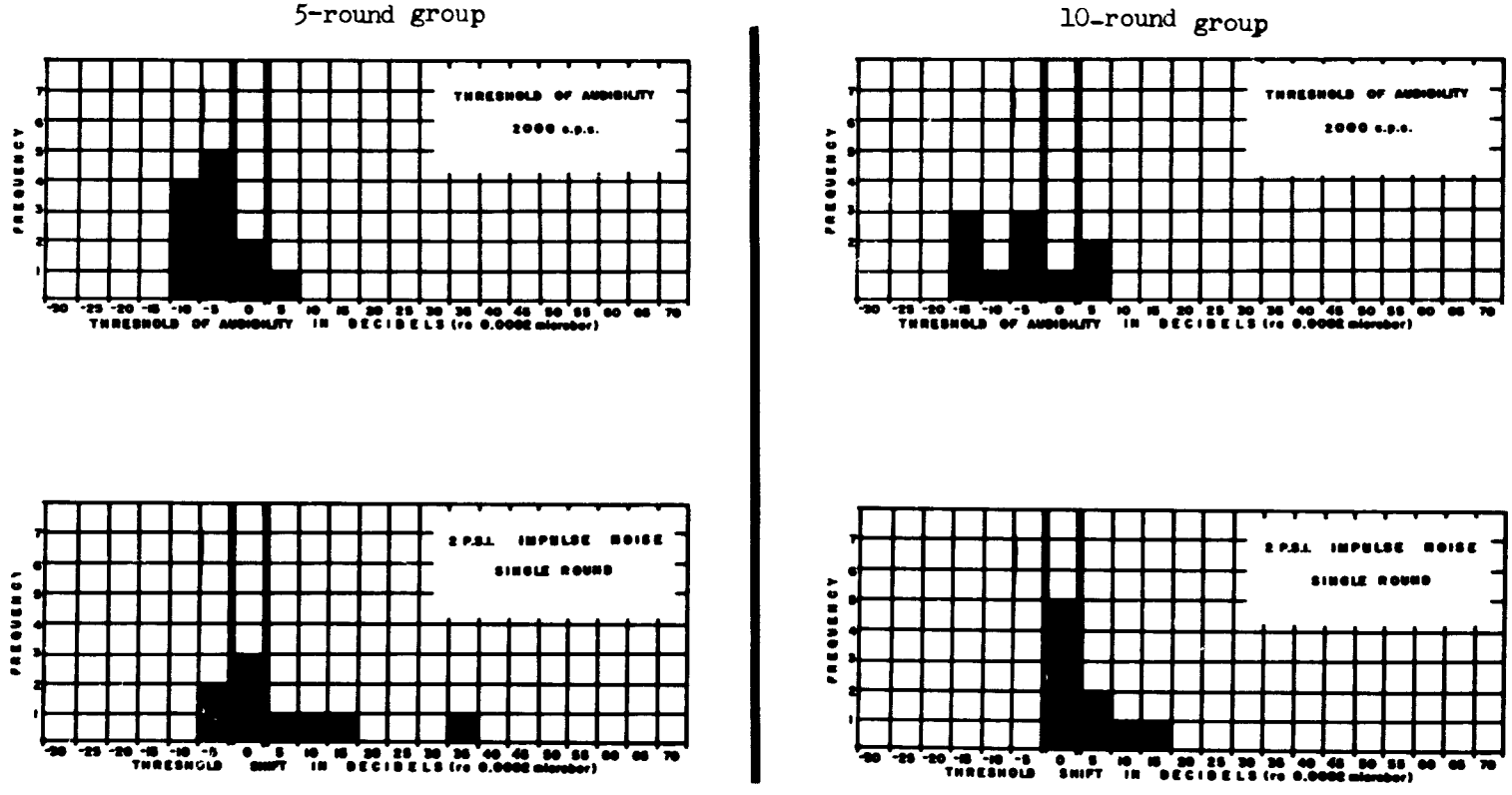


Fig. 14. HISTOGRAMS SHOWING THE PRE-FIRING THRESHOLD OF AUDIBILITY AND THE THRESHOLD SHIFTS AFTER EXPOSURE TO A SINGLE ROUND AT 2 psi FOR THE 5- AND 10-ROUND GROUPS OF SUBJECTS.

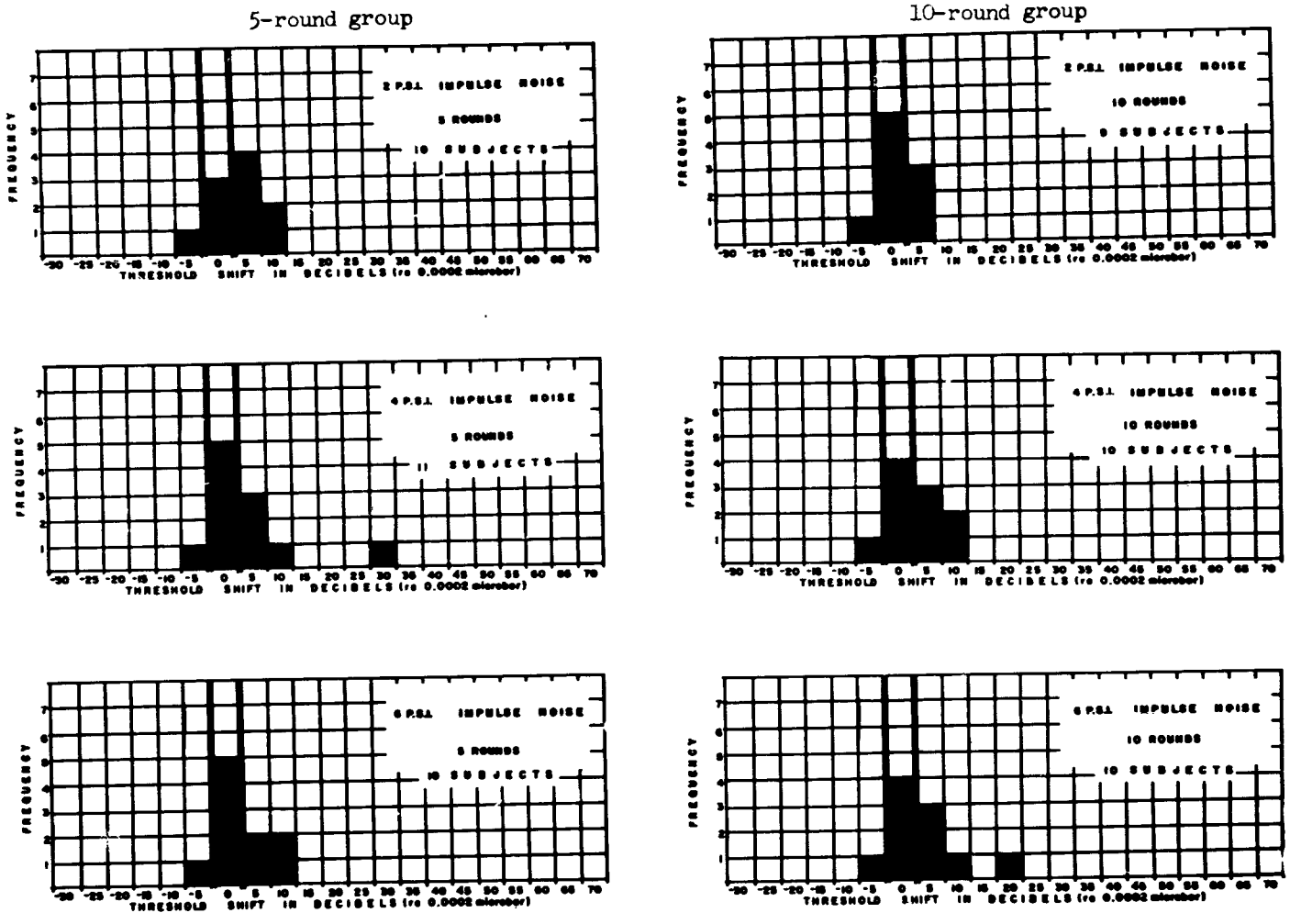
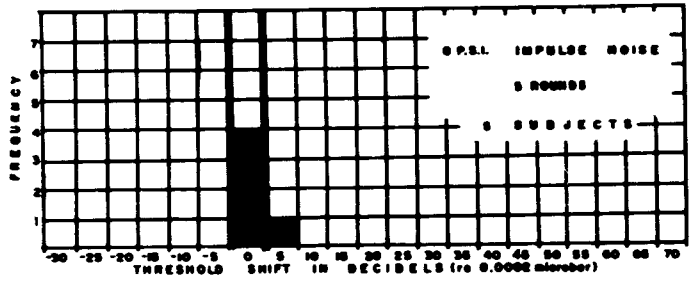
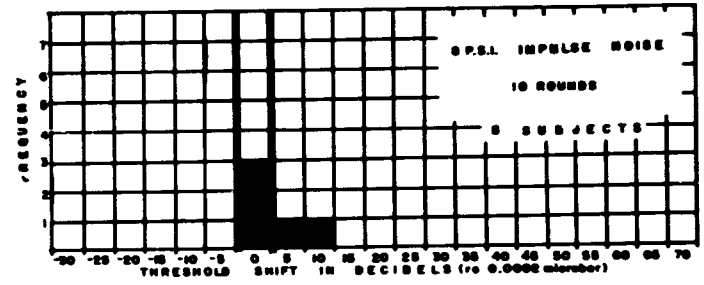


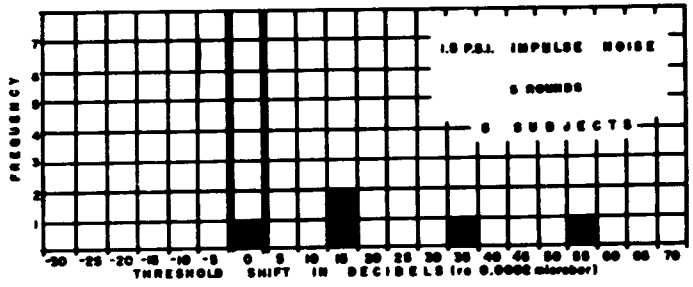
Fig. 15. HISTOGRAMS SHOWING THE THRESHOLD SHIFTS AFTER EXPOSURE TO 2, 4, AND 6 psi IMPULSE NOISES FOR THE 5- AND 10-ROUND GROUPS.

5-round group



10-round group





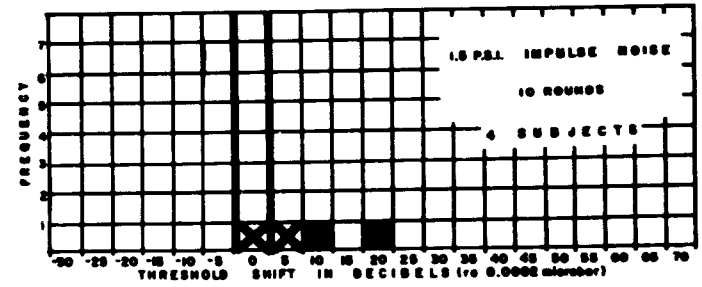


Fig 16. HISTOGRAMS SHOWING THE THRESHOLD SHIFTS AFTER EXPOSURE TO 8 psi PROTECTED OR 1.5 psi UNPROTECTED FOR THE 5- AND 10-ROUND GROUPS.

APPENDIX D

Field Test of Temporary Threshold Shifts of Crewmen

As a check on the controlled study, additional data were collected during a field test of the 105mm Howitzer XM102 with XM482 increased range round zone 8 charge conducted by the U. S. Army Artillery Board, Fort Sill, Oklahoma.

Pre- and post-exposure audiograms were conducted in the same manner as in the controlled study. The conditions under which these data were collected differ from the study as follows:

a. The XM102, 105mm Howitzer was used instead of the M2A3E2.

b. The K-5 medium-efficiency muzzle brake was used instead of the No. 8 low-efficiency brake.

c. The men were in normal crew positions.

d. Pressures were approximately 5 psi measured with paper blast gages.

e. The men were tested after exposure to one round rather than multiple rounds.

f. Experienced cannoneers were used as subjects instead of novices.

The subjects (gunner, No. 1 cannoneer, and loader) were given audiograms the day prior to exposure. It was possible to retest only the gunner immediately prior to exposure. None of the subjects had more than 10 dB TTS at 4 kc on the post-firing audiogram.

On the two succeeding days, the subjects were tested before and after exposure to one round of fire from the XM482. The audiogram readings for all the firings are given in Table 3.

After exposure to blast, the members of an experienced gun crew did not exhibit temporary threshold shifts greater than 20 dB at any frequency tested. The Army-issued noise protection ear plugs, when properly fitted to healthy men and properly inserted by each man, will protect personnel against hearing acuity loss at all positions of the XM102 with the XM482 round.

TABLE 3

Hearing Thresholds for Crew Members of XM102

Subject	Day	Threshold Acuity in dB — Left Ear 2000	3000	4000	6000	Right Ear 2000	3000	4000	6000	Frequency
Gunner	1	-15	0	-5	10	-5	10	20	10	Gunner Pre-test
	2	-15	-5	-5	5	-15	10	30	20	Pretest
		0		5		5		35		2 min after 5+ psi
						5	15	30	25	5 min after 5+ psi
		-15	-5	-5	0	-5	0	30	20	10+ min after blast exp.
	3	-10	-10	-5	5	-5	15	25	10	Pretest
		-10	-15	-5	5	-5	5	25	25	10+ min after blast exp.
		-10	- 5	-5	0	-5	10	25	15	10+ min after blast exp.
#1 Cannoneer	1	15	25	25	25	25	30	30	25	Pretest
	2	30		30		35		30		2 min after 5+ psi
						30	35	35	35	5 min after 5+ psi
	3	25	25	25	25	35	35	30	45	Pretest
		25	25	25	25	30	35	40	15	10+ min after blast exp.
		25	25	25	25	30	35	30	35	10+ min after blast exp.
Loader	1	0	0	10	20	5	0	15	15	#2 loader pretest
	2	10		15		5		20		2 min after 5+ psi
						5	15	20	10	5 min after 5+ psi
	3	10	5	20	15	10	10	20	20	Pretest
		5	5	12	25	10	10	20	15	10+ min after blast exp.

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Technical Memorandum 1-63 Unclassified
AMCMS Code 5520.12.42700.05.01

The protection which the V-51R Ear Plug provides against high-intensity impulse noise was determined for simulated rapid-fire field conditions. Twenty enlisted men were exposed to 2, 4, and 6 pounds per square inch peak overpressures generated by a 105mm howitzer. Their temporary threshold shifts were then measured at 2000 and 4000 cycles per second. The results indicated that inserting the V-51R Ear Plug without checking its fit does not give adequate protection to all personnel. It was also found that a protection-checked ear (ear plug inserted to minimize the level of a reference sound) gave adequate protection with impulse pressures up to 8 psi.

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